



**University of
Zurich**^{UZH}

**Zurich Open Repository and
Archive**

University of Zurich
University Library
Strickhofstrasse 39
CH-8057 Zurich
www.zora.uzh.ch

Year: 2012

COSMO-skymed, TerraSAR-X, and RADARSAT-2 geolocation accuracy after compensation for earth-system effects

Schubert, Adrian ; Small, David ; Jehle, Michael ; Meier, Erich

Abstract: A Synthetic Aperture Radar (SAR) sensor with high geolocation accuracy greatly simplifies the task of combining multiple data takes within a common geodetic reference system or Geographic Information System (GIS), and is a critical enabler for many applications such as near-real-time disaster mapping. In this study, the geolocation accuracy was estimated using the same methodology for products from three SAR sensors: TerraSAR-X (two identical satellites), COSMO-SkyMed (four identical satellites) and RADARSAT-2. Known errors caused by atmospheric refraction, plate tectonics and the solid-Earth tide were modeled and compensated during the analysis. Of the products analyzed, TerraSAR-X provided the highest absolute and relative geolocation accuracy.

DOI: <https://doi.org/10.1109/IGARSS.2012.6350598>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-76877>

Conference or Workshop Item

Published Version

Originally published at:

Schubert, Adrian; Small, David; Jehle, Michael; Meier, Erich (2012). COSMO-skymed, TerraSAR-X, and RADARSAT-2 geolocation accuracy after compensation for earth-system effects. In: International Geoscience and Remote Sensing Symposium, Munich, Germany, 22 July 2012 - 27 July 2012. IEEE International, 3301-3304.

DOI: <https://doi.org/10.1109/IGARSS.2012.6350598>

COSMO-SKYMED, TERRASAR-X, AND RADARSAT-2 GEOLOCATION ACCURACY AFTER COMPENSATION FOR EARTH-SYSTEM EFFECTS

Adrian Schubert, David Small, Michael Jehle, Erich Meier

Remote Sensing Laboratories, Department of Geography, University of Zurich, Switzerland
Winterthurerstrasse 190, 8057 Zurich, Switzerland
[adrian.schubert | david.small | michael.jehle | erich.meier]@geo.uzh.ch

ABSTRACT

A Synthetic Aperture Radar (SAR) sensor with high geolocation accuracy greatly simplifies the task of combining multiple data takes within a common geodetic reference system or Geographic Information System (GIS), and is a critical enabler for many applications such as near-real-time disaster mapping. In this study, the geolocation accuracy was estimated using the same methodology for products from three SAR sensors: TerraSAR-X (two identical satellites), COSMO-SkyMed (four identical satellites) and RADARSAT-2. Known errors caused by atmospheric refraction, plate tectonics and the solid-Earth tide were modeled and compensated during the analysis. Of the products analyzed, TerraSAR-X provided the highest absolute and relative geolocation accuracy.

Index Terms— SAR, COSMO-SkyMed, TerraSAR-X, RADARSAT-2, Geolocation

1. INTRODUCTION

The extremely high orbital and product geolocation accuracy of Germany's TerraSAR-X (TSX) satellite, launched in 2007 by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR), has been established in past validation studies conducted by multiple research groups (e.g. [1][2][3][4]). In particular, its high-resolution spotlight (HS) products, with resolution better than 1 m, offer one of the highest fidelities currently available to the scientific community from spaceborne sensors.

The Italian Space Agency (*Agenzia Spaziale Italiana*, ASI) launched a series of four identical SAR platforms called COSMO-SkyMed (CSM) between 2007 and 2010. Like TSX, these sensors also operate at X-Band (wavelength ~ 3 cm). With a range sampling rate and pulse repetition frequency (PRF) exceeding even those offered by TSX's HS mode, products from CSM's Enhanced Spotlight (ES) mode have the potential to produce results comparable to TSX's geolocation accuracy.

Finally, with its Ultrafine (UF) beams, Canada's C-Band (~ 5 cm wavelength) RADARSAT-2 satellite, launched in 2007, offers stripmap products with spatial resolutions of ~ 2 -3 m that far exceed the standard stripmap resolutions available from earlier spaceborne C-Band sensors (such as ENVISAT ASAR). These products represent a compromise between the larger coverage of previous stripmap modes and the highest resolution possible using spotlight configurations.

Unavoidable technical challenges for such systems are orbital stability and positional accuracy. Both set limits to the achievable localization accuracy of imaged ground targets. Apart from orbit- and sensor-specific technical challenges, achieving the highest-possible accuracy from SAR image products additionally requires correcting for at least two perturbing factors (described in [1]): (a) signal path delay (PD) due to atmospheric refraction – typically on the order of several meters, and (b) the solid Earth tide (SET), which is the periodic rising and falling of the Earth's crust on the order of 1-2 decimeters. In this study, ground measurements were surveyed using differential GPS (DGPS). Because of differences between the local and global geodetic reference frames caused by continental plate tectonics, a plate-drift model was also incorporated into our location estimates. We refer to the SET and plate tectonics together as “solid-Earth perturbations.”

2. EXPERIMENTAL SETUP

For TSX, a time series of images spanning 16 months was obtained over a fixed test site in the west of Switzerland (*Torny-le-Grand*), making it possible to validate both atmospheric refraction and SET models, while establishing the instrument's long-term stability. These goals were achieved by placing trihedral corner reflectors (CRs, two shown in Fig. 1a) at the test site, and estimating their phase centers with cm-level accuracy using DGPS. Oriented in pairs toward a given satellite track, the CRs were visible as extremely bright points in the images, providing a geometric reference set. An example of an image extract showing the appearance of two CRs is shown in Fig. 1c.

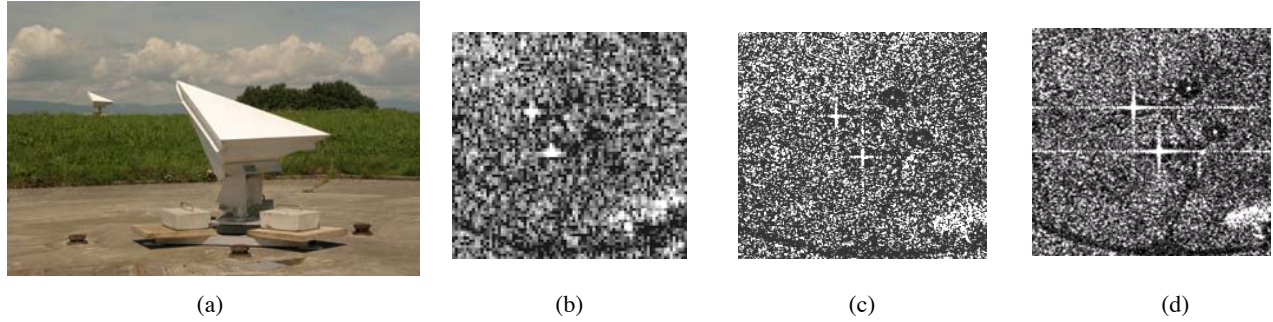


Fig. 1 Trihedral corner reflectors at *Torny-le-Grand* (Switzerland) test site (a) field deployment, (b) as seen in an ascending RADARSAT-2 UF product acquired 02.03.2010, (c) as seen in an ascending TerraSAR-X HS product acquired 24.04.2011, and (d) as seen in an ascending COSMO-SkyMed ES product acquired 22.04.2011.

TSX product © InfoTerra GmbH; COSMO-SkyMed product © ASI; RADARSAT-2 product © MacDONALD, DETTWILER AND ASSOCIATES LTD. (2010) – All Rights Reserved.

SAR images from the TSX HS mode were obtained in alternating ascending and descending orbit configurations. The highest-resolution products were selected to enable determination of their positions at the best possible precision.

In the context of a similar study for the Italian Space Agency, ten CSM ES-mode products spanning one month and covering the same test site were received in March-April 2011. Twenty further acquisitions spanning May-December 2011 were subsequently acquired over a similar test site in *Dübendorf*, Switzerland in three different modes (ES, as well as stripmap dual-polarization “PingPong” and single-polarization “Himage” modes). The appearance of the CRs in an ES product can be seen in Fig. 1d.

Finally, four RADARSAT-2 products were acquired in stripmap mode with its UF beam over *Dübendorf* during November-December 2011. For better comparison with Fig. 1c and d, Fig. 1b shows an extract around the CRs from a previously-acquired product (March 2010) over *Torny-le-Grand*, also from an ascending-orbit.

3. PROCESSING STEPS

Both Swiss test sites (*Torny-le-Grand* and *Dübendorf*) provided the opportunity to place CRs on open asphalt surfaces, guaranteeing high CR visibility. In all cases, the same methods were used to arrive at geolocation error estimates, outlined in the following steps.

- The CR phase center positions were estimated with cm accuracy using DGPS, relative to a local reference station.
- The CR’s GPS position was transformed into the global Cartesian reference frame of the satellite (WGS84), according to a plate tectonic model, and further adjusted according to a SET model (details in [1]).
- Given the timing constants and orbital state vectors from the product annotations, the CR positions were geolocated into the native range-azimuth geometry of the delivered image products. The resulting image coordinates are the

predicted CR locations after solid-Earth perturbation modeling.

- Atmospheric PD was estimated for the test site given meteorological measurements from a nearby station, according to the viewing geometry of each acquisition (details in [1] and [5]). This PD, expressed in meters, was then *added* to the predicted CR range, resulting in a final predicted CR location with solid-Earth and atmospheric PD perturbations removed.
- The predicted CR locations were subtracted from the *measured* image locations, estimated with subpixel accuracy using oversampling.

4. RESULTS

The TSX study [1] was able to demonstrate that when the delivered product timing annotations are adjusted for PD and solid-Earth perturbations using simple models, the HS products deliver unprecedented geolocation accuracy on the order of ~ 10 cm with a standard deviation of ~ 3 -4 cm. A scatter plot of the differences between modeled and imaged CR locations is shown in Fig. 2. No bias between CRs imaged from ascending and descending orbits can be seen. Furthermore, this accuracy was maintained for the duration of the 16-month test period.

The same geolocation equations were applied to the CSM ES and RADARSAT-2 UF products as in the TSX case (including mitigation of solid-Earth perturbations and atmospheric PD).

In comparison with TSX HS mode, CSM’s higher range bandwidth of ~ 400 MHz and slightly higher PRF of ~ 4 KHz enable higher image spatial resolution. However, product geolocation accuracy is largely dependent on the quality of the provided orbital state vectors (satellite positions) and the range and azimuth timing parameters. As this study demonstrates, TSX currently appears to provide orbital and timing annotations that are superior to those of CSM. The differences between the predicted and imaged CR locations

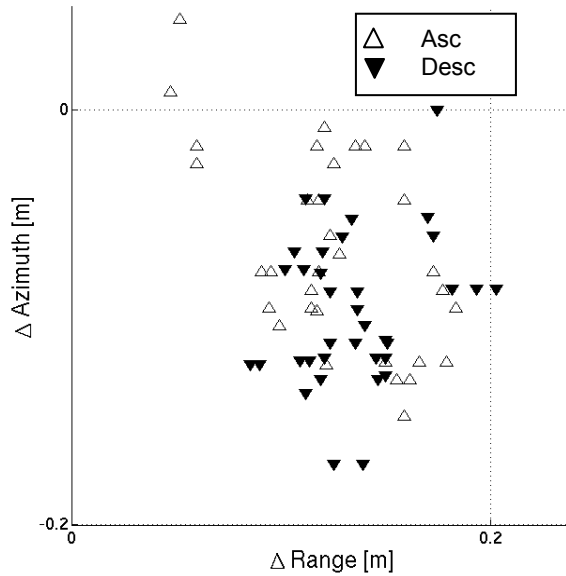


Fig. 2 TSX spotlight-mode errors with correction for solid-Earth perturbations and atmospheric PD (from [1])

are shown for all CSM products in Fig. 3, where solid-Earth perturbations have been modeled and removed. In Fig. 3a, the data points are color-coded by imaging mode (product type). As expected, the ES mode is more accurate than the stripmap modes; it has a range error of 1.1 ± 0.7 m and an azimuth error of -0.2 ± 0.5 m (mean \pm standard deviation). This result is roughly consistent with another brief study into CSM's spotlight-mode geolocation accuracy [7]. Note that Fig. 3a does *not* yet include PD mitigation.

Fig. 3b shows the same scatter plot as in Fig. 3a, but color-coded according to satellite number. There are no clearly visible biases between them, suggesting that at least the largest geolocation error sources are independent of the satellite number.

In Fig. 3c, the modeled atmospheric PD has been added to the predicted ranges, shifting the error cloud to the right and *increasing* the absolute errors by several meters. The error spread has also only minimally improved. This decrease in quality with PD mitigation suggests two possibilities: (1) a nominal, undocumented PD correction was incorporated into the delivered timing annotations during sampling window start time (SWST) bias calibration, i.e. atmospheric PD was not separated from other biases during SWST bias calibration, or (2) no PD correction has been implemented in the delivered data, but the annotated range SWST bias is incorrect by several meters (implying the need for re-calibration). It should be noted, however, that several annotation-related questions are still under discussion between our research group and ASI, leaving open the possibility for improved results in the near future.

For RADARSAT-2, some preliminary results were reported in [6]. Since then, four additional UF products were acquired over another test site; the geolocation accuracies are similar to those previously reported. All had

range errors under 2 m but large azimuth errors ~ 10 m. As was the case for CSM, including compensation for atmospheric PD actually had the effect of *increasing* the geolocation error, rather than decreasing it.

Since no definitive conclusions can be drawn based on such a small sample size (six products total), the results are reported here only in a preliminary fashion.

5. CONCLUSIONS

The consistently high geolocation accuracy of TSX products has been previously established [1][3]. It remains the reference for geolocation accuracy and stability.

Although CSM spotlight products provide higher spatial resolution, the annotated orbital and timing parameters currently do not permit geolocation at the sub-meter level. Whether this is due to inaccuracies in the annotations themselves, or to their misinterpretation, is still being analyzed in collaboration with ASI.

The C-Band RADARSAT-2 UF products provide range geolocation accuracies on the order of a meter; however, large errors on the order of 10 m were observed in the azimuth dimension. Given the limited number of products currently available for study, no definitive conclusions can be drawn from the results to date.

6. REFERENCES

- [1] Schubert A., M. Jehle., D. Small, and E. Meier, "Mitigation of atmospheric perturbations and solid-Earth movements in a TerraSAR-X time-series," *J. of Geodesy*, 86(4), DOI 10.1007/s00190-011-0515-6, pp. 257–270, 2012.
- [2] Schubert A., M. Jehle., D. Small, and E. Meier, "Influence of Atmospheric Path Delay on the Absolute Geolocation Accuracy of TerraSAR-X High-Resolution Products," *IEEE Transactions on Geoscience and Remote Sensing*, 48(2), pp. 751–758, Feb. 2010.
- [3] Eineder M., C. Minet, P. Steigenberger, X. Cong, and T. Fritz, "Imaging Geodesy – Toward centimeter-level ranging accuracy with TerraSAR-X," *IEEE Transactions on Geoscience and Remote Sensing*, 49(2), pp. 661–671, Feb. 2011.
- [4] Eldhuset K. and D. J. Weydahl, "Geolocation and Stereo Height Estimation Using TerraSAR-X Spotlight Image Data," *IEEE Transactions on Geoscience and Remote Sensing*, 49(10), pp. 3574–3581, Oct. 2011.
- [5] Jehle M., D. Perler, D. Small, A. Schubert, and E. Meier, "Estimation of atmospheric path delays in TerraSAR-X data using models vs. measurements," *Sensors*, 8(12), DOI 10.3390/s8128479, pp. 8479–8491, Dec. 2008.
- [6] Small D., L. Zuberbühler, A. Schubert, and E. Meier, "Terrain-flattened Gamma Nought Radarsat-2 Backscatter," *Canadian J. of Remote Sensing*, 37(5), pp. 493–499, Oct. 2011.
- [7] Bresnahan P.C., "Geolocation Accuracy Re-Evaluation of Cosmo-Skymed Spotlight and Stripmap Imaging Mode Products", *Proc. of Joint Agency Commercial Imagery Evaluation (JACIE) Civil Commercial Imagery Evaluation Workshop*, Boulder, Colorado, USA, Mar. 2011.

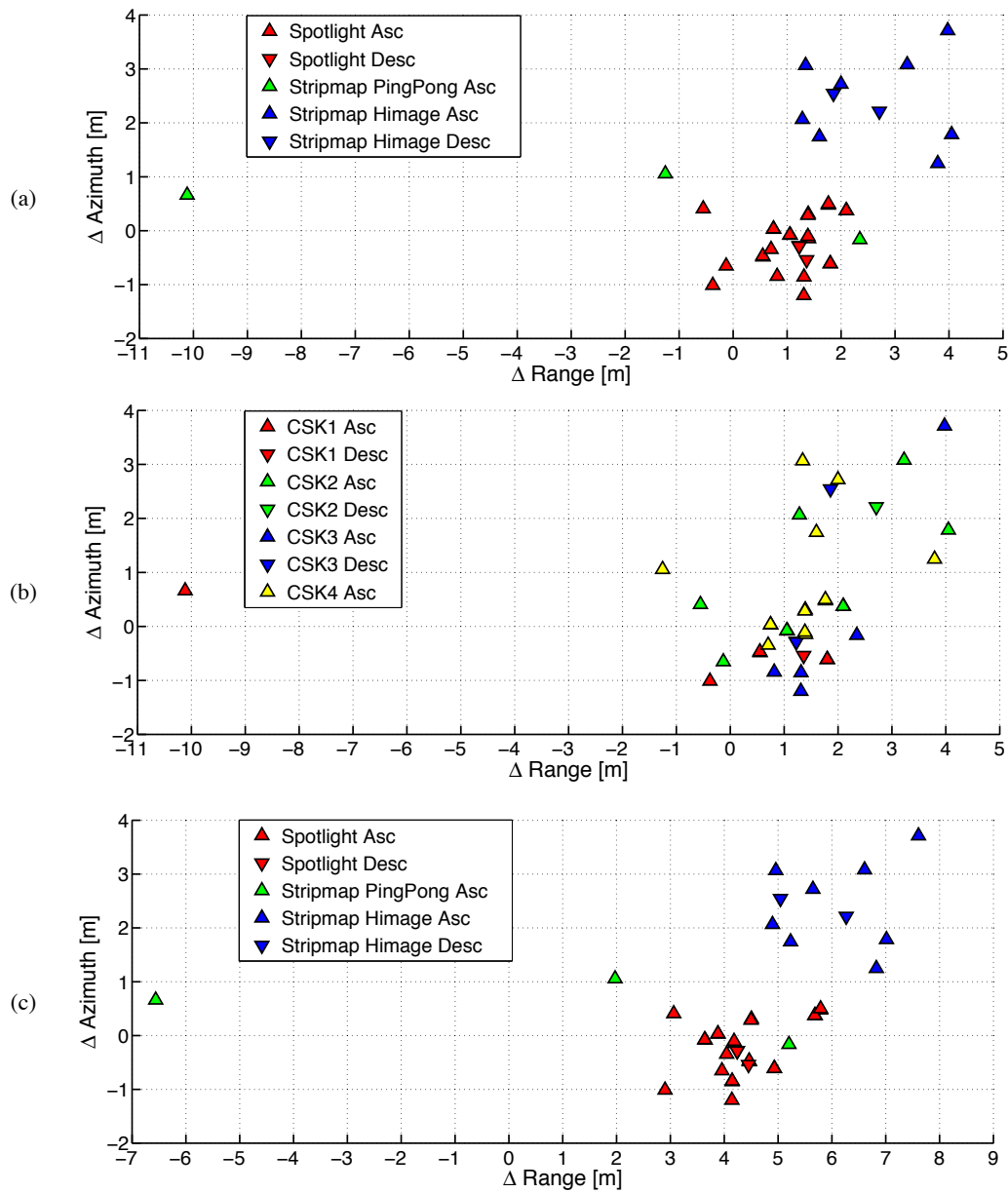


Fig. 3 CSM errors with correction for solid-Earth perturbations and (a) *without* correction for PD; colors indicate imaging mode, (b) *without* correction for PD; colors indicate satellite, (c) *with* correction for PD; colors indicate imaging mode